

****TITLE****

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X-ray Statistical Properties of the central cool component in clusters of galaxies

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Abstract. Central cool gas component that is often observed from a well-relaxed cluster system has long been interpreted as a consequence of “Cooling Flow” (CF), radiative cooling followed by inflow of Intra-Cluster Medium (ICM). However, recent XMM-Newton spectroscopy has shown no signatures of cooler gas phases below certain temperatures in typical CF clusters (A1795, Tamura et al. 2001; A1835, Peterson et al. 2001). This contradicts the conventional CF model or at least requires a major revision of the model. In order to investigate statistical properties of the central cool component, we performed systematic analysis of *ASCA* data on 85 clusters. We found that 1) temperature of the central cool component strongly depends on the temperature of the main ICM, 2) the cool component is selectively found around a brightest cluster galaxy (BCG) that coincide with the X-ray peak position, and 3) the luminosity-temperature (L - T) relation of the cool component shows nice agreement with the L - T relation of the main ICM. Together with the previous observational fact that, in some of the “CF” clusters, the total gravitating mass is clustering in two distinct spatial scales, a main cluster component and a second small-scale system, we conclude that the central cool component is associated with the second small-scale self-gravitating system that is immersed in the host cluster, and the cool component temperature reflects the gravitational potential depth.

1. Sample and *ASCA* analysis

For the study we used brightest 85 clusters observed with *ASCA* whose redshifts distribute from 0.004 to 0.201 with a median of 0.046. From each GIS and SIS instrument, a spectrum over a central region of $2'$ radius and one outside $2'$ radius were accumulated. We fitted each set of *ASCA* spectra with the two-temperature model (2T model), in which a hot component is filling entire cluster region, while in the central region a cool component is allowed to coexist with the hot component forming two-phase plasma. We then obtained X-ray luminosity in 0.1-2.4 keV band and temperature of cool and hot component, L_c , T_c , L_h , and T_h . Full results are given in Ikebe et al. (2001). An example of the 2T model fit is shown in Fig. 1 for Abell 1795, which has one of the brightest central cool component.

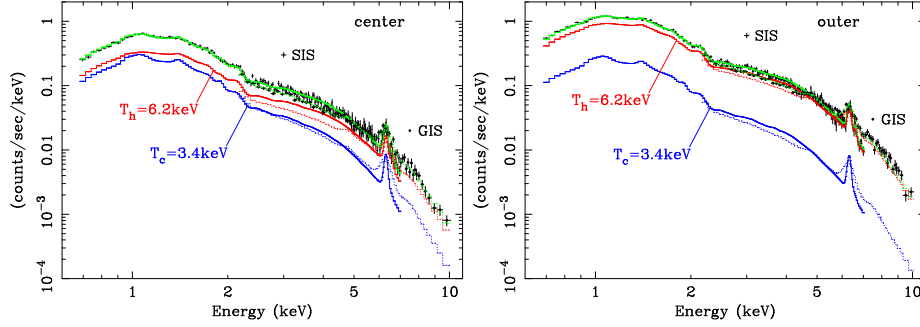


Figure 1. *ASCA* spectra of Abell 1795 extracted from the center (left) and outer (right) regions. Crosses and filled circles show SIS and GIS data, respectively. Flux mixing effects due to the largely extended point-spread functions of X-Ray Telescope have been taken into account and the four spectra are fitted simultaneously with the 2T model. The best-fit model for the SIS and GIS are illustrated with solid and dotted lines respectively.

2. Validity confirmation of the 2T model with XMM-Newton data

The validity of the 2T model was tested with the latest X-ray data of Abell 1795 taken with XMM-Newton. The 11 annular spectra of EPIC-PN were simultaneously fitted with the 2T model, where each annular spectrum is modeled with sum of two isothermal component, and each component is assumed to have common temperature throughout all radii. The fit is good and the best-fit two temperatures are derived to be $T_c = 3.3$ keV and $T_h = 6.4$ keV, which are compared with the temperature profile obtained with the single-phase model (Fig. 2). The T_c and T_h nicely agree with the central coolest temperature and that of the isothermal component in the outer region, respectively. Therefore, the 2T modeling is valid to the most advanced X-ray data and usable to characterize the property of the central cool component and the surrounding ICM.

3. Results and Discussions

Based on the results from the 2T model fitting to the *ASCA* data of the 85 selected clusters, we investigated various correlations. In the study, we classified the cluster sample into three groups, which are Strong Cool Component (SCC), X-ray Dominant (XD) and non-X-ray Dominant (nXD). An SCC cluster is defined as one showing a very strong (statistically very significant) cool component in the *ASCA* spectrum. Among the rest of the clusters, one in which the X-ray peak coincides with the Brightest Cluster Galaxy (BCG) is classified as an XD cluster, while nXD is defined as one without such a galaxy. All the SCC clusters turned out to be XDs, too.

For the SCC clusters, we determined the temperatures and emission measures of each cool and hot component. Figure 3(a) shows the cool component luminosity as a function of the cool component temperature for the SCC clusters. A positive correlation is clearly seen. Figure 4 shows the correlation between

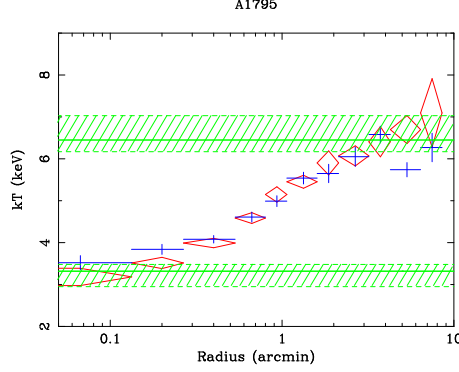


Figure 2. The temperature profile of Abell 1795. The results from the single-phase model given in Tamura et al. (2001), in which each annular spectrum is fitted with an isothermal plasma emission model, are reproduced with crosses (XMM/EPIC-MOS) and diamonds (PN). The cool and hot component temperatures, T_h and T_c , derived with the 2T model are illustrated with crosshatched regions.

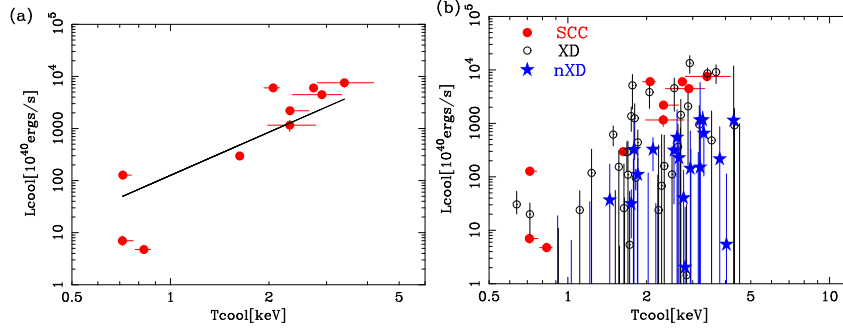


Figure 3. (a) The L_c - T_c relation for the SCC clusters. The line is the best-fit power-law function to the L_h - T_h relation illustrated in Fig. 6. (b) The L_c - T_c relation for all the sample clusters. Filled circles, open circles, and filled stars specify SCC, XD, and nXD clusters, respectively.

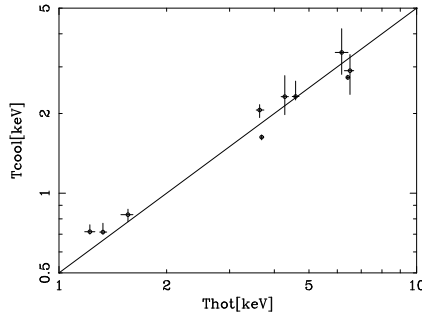


Figure 4. T_c - T_h relation for the SCC clusters. The line represents $T_c = T_h/2$.

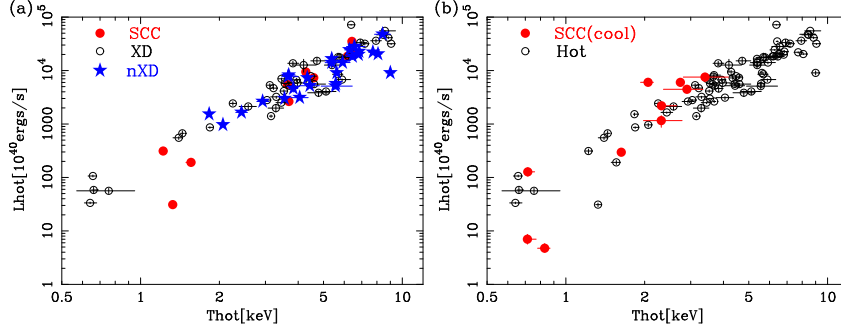


Figure 5. (a) The L_h – T_h relation for all the sample clusters. Filled circles, open circles, and filled stars specify SCC, XD, and nXD clusters, respectively. (b) The L_c – T_c relation for the SCC clusters (filled circles) is overlayed on the L_h – T_h relation (open circles).

the two temperatures of the hot and cool component for the SCC clusters. Surprisingly, the ratios between the two temperatures, T_c/T_h , is virtually constant and the relation, $T_c = T_h/2$ well represents the correlation.

For clusters that do not show very strong cool component, i.e. non-SCC clusters, we fixed T_c at the half value of each mean temperature derived with a single-temperature model fitting, according to the $T_c = T_h/2$ relation. The luminosity of the cool component thus estimated for the non-SCC clusters is illustrated in Fig. 3(b). The results of the SCC clusters are also overlayed. SCC and XD clusters exhibit systematically more luminous cool component than nXD clusters. Actually, many of nXD clusters give only upper limit to L_c .

We obtained the L – T relation of the hot component, which is illustrated in Fig. 5(a). Unlike for the cool component, the three classes do not show any systematic difference. It is then clearly shown that the X-ray characteristics of the XD and nXD clusters are segregated mainly by the central cool component. To compare with the L – T relation of the cool component would be very interesting. In the Fig. 5(b), the L_c – T_c relation for the SCC clusters shown in Fig. 3 is overlayed on the L_h – T_h relation. A surprising agreement is clearly seen. The best fit power-law function to the L_h – T_h relation is compared with the SCC L_c – T_c relation in Fig. 3. The similarity of the two L – T relation suggests that both the cool and hot components are related to individual gravitational bound objects. Therefore, the cool component can be naturally interpreted as ICM filling a self-gravitating system whose size is comparable to a giant elliptical galaxy or a group of galaxies, which is immersed in the host cluster.

References

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- Peterson et al. 2001, A&A, 365, L104